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Articulating strategies to address heat resilience using spatial optimization and temporal analysis of utility assistance data of the Salvation Army Metro Phoenix

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ABSTRACT

Long-term community resilience, which privileges a long-view look at chronic, slow-moving issues affecting communities, has begun to draw more attention from researchers and policymakers. In the Valley of the Sun, resilience to heat is both a necessity and a way of life. Solutions are ubiquitous but nevertheless still in demand over the long, hot summers in the Phoenix, Arizona metropolitan area. Residents heavily rely on air conditioning (AC) for relief from heat stress, illness, and to prevent indoor heat-related deaths. However, paying for the electricity to keep homes cool can be expensive and the electric bills can be cost prohibitive for many low-income individuals and families. Local government agencies, non-governmental organizations (NGOs), and charitable organizations have programs that provide financial assistance for qualified applicants offering limited relief from electricity costs. To better understand the utility assistance landscape in the Phoenix metropolitan area as a contributor to heat resilience among vulnerable communities, we created a collaborative team of individuals from the university and the Salvation Army, one of the more than 80 organizations that provides emergency economic aid for low-income families to pay high-cost electricity bills, to articulate insights about systemic efficiencies and efficacies, from a data-informed perspective. We utilized exploratory data analysis and advanced spatial analytical methods with the Salvation Army, to build a shared understanding of knowledge gaps and verified hunches. Our collaborative research confirms that minority groups (African American and Native American) disproportionately require assistance. Meanwhile, 30% of the travel time and distance to intake interviews could be saved by switching from zip code-based assignment systems to address-based assignment systems. Budgeting across empirically identified temporal patterns of need could offer resilience benefits to the most vulnerable. As a result of this community research partnership, data from the Salvation Army reveals the character and dimension of critical challenges within the utility assistance system as a whole, informs both immediate solutions and builds a knowledge base for transforming future operations for the organization, while it shapes broader conversations across the community of service providers about heat resilience in both spatial and temporal terms.

1. Introduction

Resilience, especially the concept of community resilience, is traditionally defined as how communities prepare for, respond to, and recover from natural hazards and disasters such as hurricanes and earthquakes (Cutter, Ash, & Emrich, 2014). Short-term disaster resilience has been extensively explored and discussed via different indicators of resilience (social, economic, institutional, housing/infrastructural, environmental, and community capital) (Cutter, Burton, & Emrich, 2010) with various geospatial data sources (i.e. social media, remotely sensed imagery) and methodologies (i.e. machine learning, Bayesian network, and cyberinfrastructure) (Cai, Lam, Zou, & Qiang,

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2018; Li, Lam, Qiang, Zou, & Cai, 2015; Zou, Lam, Cai, & Qiang, 2018). Great attention is given to community disaster resilience which dominates most of the existing academic literature and public discussion. However, long-term community resilience, which privileges a long-view look at chronic, slow-moving issues affecting communities, has begun to draw attention from researchers and policymakers. It is important to understand how communities can learn, adapt and respond to long-term social, economic, and environmental community stresses such as chronic poverty, sea level rise, and recurring drought conditions (Beheshtian, Donaghy, Richard Geddes, & Oliver Gao, 2018; Ranjan Ram, 2014). Existing literature has explored some issues of long-term community resilience by looking at care for elderly people (Janssen, Van Regenmortel, & Abma, 2011), economic resilience with tourism decline (Bec, McLennan, & Moyle, 2016), and environmental resilience with food security (Barthel & Isendahl, 2013).

Among all the long-term community stresses, heat/cold weather exposure, including extreme events as well as longer summers/winters, poses a growing health threat to residents in the United States. Although extreme cold weather events and cold-related deaths have received more attention from the media and dominate existing academic research, extreme heat was actually responsible for the largest number of 2018 weather fatalities in the United States with approximately 108 deaths (National Weather Service, 2018). The actual number of deaths, however, is believed to be higher because extreme heat is often a contributing factor for other causes of death, such as cardiovascular disease and chronic ischemic heart disease (Shen, Howe, Alo, & Moolenaar, 1998) but usually not reported as such. This is particularly true for heat vulnerable individuals (i.e., elderly adults, infants and children) who are susceptible to such illnesses, and, importantly, low-income individuals and families who live in low energy efficiency dwellings and cannot afford to pay high utility bills due to the use of an AC system (Kovats & Hajat, 2008).

Various strategies can be used to alleviate exposure to extreme heat and reduce heat risks. Examples include AC system maintenance and upgrade, use of urban green and blue infrastructure, and housing energy efficiency improvement (Fraser et al., 2017; Wentz & Gober, 2007; Zhao, Sailor, et al., 2018; Zhao, Yang, et al., 2018). AC is widely used to reduce heat stress and indoor heat-related morbidity and mortality of city residents from the extreme heat exposure. However, due to the high demand of electricity usage, many low-income individuals and families and fixed-income seniors cannot afford the cost of running AC for the entire summer without interruption (on average $US 200–300 per month for a single-family household). The ability to pay is unevenly experienced by residents according to their economic vulnerability. The cost to keep cool can be prohibitive for many low-income individuals and families. Without the operation of AC, low-income individuals and families lose their household energy security and are potentially exposed to extreme indoor heat stress (Cook et al., 2008; Day, Walker, & Simcock, 2016). To avoid extreme indoor heat stress, families seek alternatives such as requesting emergency utility assistance to pay a small part of their utility bills or stay with other family members.

At least 80 known organizations including local governments, non-governmental organizations (NGOs), and charitable organizations of Maricopa County offer programs that provide utility assistance for qualified applicants to fulfill their utility assistance need and relieve their financial burden. The challenge, however, is that the demand for utility assistance as measured by either applications for aid, or eligibility statistics, greatly outstrips the community's ability to respond. For example, among the 467 cases of indoor heat-related deaths in Maricopa Country from 2006 to 2018, an AC unit was present in most of the cases (84.2%). However, it was non-functioning in 55.8 percent of cases, the household was without electricity in 10.0 percent of cases, and it was simply not in use in 25.4 percent of cases (Maricopa County Public Health Department, 2019). This could be interpreted as consisting of mandatory shut-offs due to nonpayment, voluntary shutoffs to reduce costs, or lack of extra money for AC repair and maintenance. Therefore, the pressure is great to ensure that such limited utility assistance resources are distributed efficiently, and with efficacy, reaching those who need it most, where they need it most, and when they need it the most, to build overall resilience to heat in the Phoenix metro community.

The overarching goal of our collaborative research in heat resilience is to understand the character and dimension of critical challenges within the utility assistance system in order to participate in data-informed, broader conversations across the community of service providers about the need to ensure that the limited resources address the greatest need, both in spatial and temporal terms. The specific purpose of the study presented in this article is to share the results of a data and analysis collaboration with the Salvation Army Metro Phoenix, one major actor in that landscape, as a means to empirically discover and articulate strategies that may be adopted by this organization or as lessons to be shared across the utility assistance system as they evolve to respond to the growing demand. The Salvation Army Metro Phoenix is an integral research partner. Their perspectives are embedded throughout this article. These results represent a first step to understand community resilience via utility assistance system under extreme heat, as part of the Knowledge Exchange for Resilience vision to share data, analytical skills, and knowledge among community actors to improve community resilience in Maricopa County.

2. Background

Successfully articulating empirically derived solutions in an applied geographic research context relies on authentic engagement with community problems and with community data. Our core team included researchers from Arizona State University and knowledge producers from within The Salvation Army Metro Phoenix, from mid-2018 to early 2019.

The Salvation Army is an international charitable organization that was originally established in London in 1865 (Our history | The Salvation Army, 2019), and is a faith-based organization with the international mission to meet human needs and help people in crisis (i.e. homelessness, unemployment, loneliness) without discrimination (Our Mission, Vision and Values | The Salvation Army, 2019). Currently, the Salvation Army serves in more than 130 developed and developing countries in the world and provides various assistance and humanitarian aid such as utility assistance, homeless hostels, children's homes, and hospitals (The Salvation Army International - Statistics, 2019). The Salvation Army Metro Phoenix provides services to help individuals and families who find themselves in crisis-based circumstances throughout the Phoenix metropolitan area. It has multiple office locations across the Phoenix Metropolitan area including the Phoenix Family Services, Sun City Corps, Chandler Corps, Glendale Corps, etc. Services include food box assistance, supplemental nutrition assistance program, utility assistance, and rental assistance. All services are accomplished through education, advocacy, financial assistance, and local partnerships. The goal of the Salvation Army Metro Phoenix is to alleviate crisis situations by preventing utility service disconnection, supplementing currently existing energy assistance resources, and identifying additional sources of support. The target population are individuals and families within the Phoenix metropolitan area, who face an economic crisis or hardship.

Particularly, the Salvation Army Metro Phoenix has energy assistance funds (cooling expenses in summer or heating costs in winter) to provide utility assistance to Phoenix-based households who need assistance in managing their energy burdens stemming from crisis. For more than 20 years, the Salvation Army has teamed up with government, NGOs, state utility companies, and area utility customers to provide financial assistance to those people in need.

Because Arizona received the lowest LIHEAP funding per capita in 2019 (Low Income Home Energy Assistance Program (LIHEAP) (2019) and the LIHEAP funding formula is heavily biased toward the cold weather areas of United States in the Northeast (Hernández, 2016; Teller-Elsberg, Sovacool, Smith, & Laine, 2016). The Salvation Army

established its own utility assistance program named SHARE (Service to Help Arizonans with Relief on Energy) funding, which is donated by state utility companies (i.e., the Salt River Project, the Arizona Public Service, and the Southwest Gas) and area utility customers. Emergency assistance is given to people who, due to crisis situations, are unable to pay their basic household energy bills and have exhausted all other potential sources of aid. Assistance is limited to one grant per year, per recipient. Because they are typically in crisis, utility assistance recipients are also often beneficiaries of other services as well.

However, the Salvation Army Metro Phoenix experiences budget limitations and has faced service infrastructure centralization measures to cut costs. Because of the high number of qualified vulnerable individuals and families who need utility assistance during the summer that come to the Salvation Army, they can only provide limited assistance from available LIHEAP and SHARE funds. In addition to limited budgets, the organization experiences uncertain variations of SHARE donations from year to year, which makes it difficult to plan ahead for funding allocation and distribution. Further, the Salvation Army Metro Phoenix has had to centralize their service areas to Central City of Phoenix as a means to reduce staffing and operational costs.

3. Study area and data

3.1. Study area

The study area is the service area for the Salvation Army Metro Phoenix within the Phoenix metropolitan area, Maricopa County, Arizona (Fig. 1). In 2017, the Phoenix metropolitan area was home to over 4.7 million residents, who together reside in 9 major cities including Phoenix, Scottsdale, Mesa, Tempe, Glendale, Chandler, Gilbert, Peoria, and Surprise (U.S. Census Bureau, 2017). Maricopa County ranks one of the fastest growing counties in the United States in both population size and urban area (Wang, Myint, Wang, & Song, 2016). During winter months, the annual average temperature is around 22 °C. This, along with a low cost of living, over 300 days of sunshine, and social and cultural amenities make the region an attractive relocation destination. The population growth has inevitably resulted in rapid urban expansion in the past few decades, which has exacerbated many adverse environmental and social impacts such as raised pollution levels (Vlachokostas, Achillas, Michailidou, & Moussiopoulos, 2012), increased energy consumption (Zhang & Lin, 2012), and heat discomfort and death (Harlan, Declet-Barreto, Stefanov, & Petitti, 2012), and extended heat waves (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006). The pleasant wintertime temperatures are in contrast, however, to severe high summertime temperatures, manifest in both extreme days of exposure and chronic high heat trends. Summer temperatures, which can exceed 48 °C, put individuals at risk to heat illness and death. Utility bills for residents are on average 6% higher than the national average with annual income levels that are, on average, 9% less than the national average (U.S. Census Bureau QuickFacts, n.d.). The indoor heat death cases have continued to increase in the Phoenix metropolitan area over the past 5 years (Harlan et al., 2012; Putnam et al., 2018), which has put many low-income families who struggle to pay for AC at risk.

3.2. Data

The data used by our team came from the Salvation Army utility assistance data from May 2015 to August 2018 and Phoenix metropolitan area demographic characteristics from the American Community Survey (ACS) 2013–2017 5-Year Estimates. The utility assistance data were extracted from the Salvation Army central management system. The Salvation Army data includes the utility assistance yearly budget from May 2015 to April 2018, monthly budget, caseloads, and approved/turn away case numbers from January 2017 to August 2018,

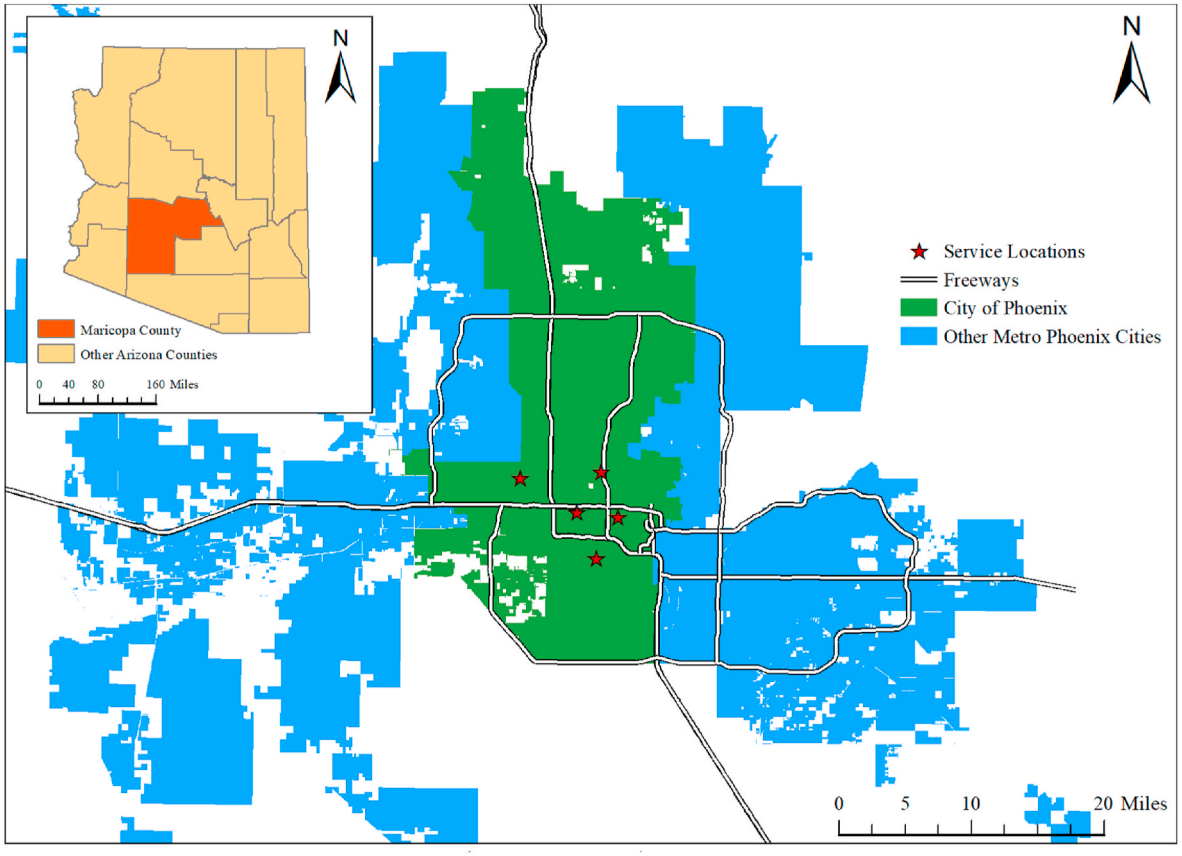


Fig. 1. Study area.

and office locations/addresses of the Salvation Army from 2015 to 2018. We also analyzed client information including family demographics (i.e., household size, number of children, household income and benefits), client home addresses, and office locations for client interviews. U.S. Census data for the City of Phoenix were downloaded from ACS 2013–2017 5-Year Estimates (US Census Bureau, 2018).

3.3. Analytical approach

We calculated descriptive statistics of the population of utility assistance clients and compared those to the general population within the City of Phoenix. The analysis aims to explore whether there are statistical differences between these populations with respect to income, household size, number of children, race, ethnicity, gender, and household type.

Beyond descriptive statistics, the analysis in this paper consists of optimizing the travel distance between utility assistance client home locations and the Salvation Army interview office locations. Prior to receiving financial aid, clients are required to attend an in-person interview with the Salvation Army to determine eligibility. The method to assign utility assistance clients to an interview location is based on zip codes, which does not minimize client travel time and distance. We experimentally reformulated the assignment process as a traditional location-allocation problem (p-median problem) (Church & Murray, 2009). The location-allocation problems are a traditional set of problems in discrete location theory (Daskin, 2013). Common examples include locating public service locations such as libraries, courts, post offices, and many others. The allocation part determines who (the clients) is served by which facility (the Salvation Army offices) in order to minimize the travel cost. The mathematical representation for the p-median problem used to assign utility assistance applicants to their nearest Salvation Army facilities is:

Consider the following notation:

i,j = index of demand points and potential facility sites, respectively.
I, J = set of demand points (clients' homes) and potential facility sites (Salvation Army service offices), respectively.
d_{ij} = shortest travel distance or travel time from demand point i to potential facility site j
a_i = amount of demand in point i (number of clients).
p = number of facilities to be located

$$Y_j = \begin{cases} 1, & \text{if facility at site } j \text{ is located} \\ 0, & \text{otherwise} \end{cases}$$

$$X_{ij} = \begin{cases} 1, & \text{if demand } i \text{ is served by facility } j \\ 0, & \text{otherwise} \end{cases}$$

$$Minimize \sum_{i \in I} \sum_{j \in J} a_i d_{ij} X_{ij} \quad (1)$$

Subject to:

$$\sum_{j \in J} X_{ij} = 1 \ \forall i \in I \quad (2)$$

$$X_{ij} \leq Y_j \ \forall i \in I \text{ and } \forall j \in J \quad (3)$$

$$\sum_{j \in J} Y_j = p \quad (4)$$

$$Y_j = \{0, 1\} \ \forall j \in J \quad (5)$$

$$X_{ij} = \{0, 1\} \ \forall i \in I \text{ and } \forall j \in J \quad (6)$$

The objective, (1), is to minimize total weighted allocation travel distance/time. Constraints (2) are allocation conditions requiring each demand point i to be served by a facility (every client must attend an interview in one of the Salvation Army facilities). Constraints (3) restrict allocations of demand i to only sites j that have been chosen for opening a facility (clients can only do the interview in open Salvation Army facilities). Constraints (4) specifies that p sites will be selected for service facilities. Finally, constraints (5) and (6) impose binary requirements. Since we cannot control the centralization process of the Salvation Army from the existing data, we fixed the service office locations (j) and do not add extra locations when solving the p-median problems. We solved the p-median problem by using the location-allocation analysis components in the ArcMap 10.6 Network Analyst.

4. Results

4.1. Descriptive statistics

Table 1 reports on descriptive statistics of clients who received utility assistance from the Salvation Army compared to all residents of City of Phoenix (U.S. Census Bureau, 2019). As the data show, most of the families who request utility assistance have larger household size and more children, and are below the 50% 2017 federal poverty level for a 3-person household ($10,210), even though eligibility includes families making up to 150% federal poverty level. In addition, we observe a higher percentage of Black/African American (43.9%) and American Indian/Alaska Native (7.3%) compared to the overall population, suggesting that minority groups are more likely to request utility assistance. Interestingly, women are far more likely than men to request utility assistance (61.2% vs. 38.8%). In addition, 41.0% of the families are raising children with a single adult female, and 21.8% of the households are single women or single men (living alone). From the demographic

Table 1
Descriptive statistics of family household characteristics.

	Utility Assistance Group	ACS 2013–2017 5-Year Estimates in the City of Phoenix[a]	
Household size (Mean)	3.28	2.59	*
Number of children (Mean)	1.64	0.69	*
Household income and benefits per year (Mean)	$9,653.16	$20,420[b]	*
Ethnicity (%)			
Hispanic	32.7	42.5	*
Non-Hispanic	67.3	57.5	*
Gender (%)			
Male	38.8	49.8	*
Female	61.2	50.2	*
Race (%)			
White	47.3	71.9	*
Black or African American	43.9	6.9	*
American India or Alaska Native	7.3	2.0	*
Asian	0.2	3.6	*
Native Hawaiian or other Pacific Islander	0.2	0.2	
Two or More Races	1.1	3.7	*
Household Type (%)			
Families with single female head of household	41.0	15.1	*
Families with single male head of household	3.2	6.9	*
Families with two adult parents	19.6	41.5	*
Single women and men	21.8	28.3	*
Other	14.4	8.2	*

Note: n = 1,666; * indicates difference between utility assistance group and ACS 5-year estimates is significant at $p < 0.05$.
[a] The ACS data were obtained from American FactFinder.
[b] Federal poverty level for a 3-person household based on 2017 U.S. poverty guidelines (2017 Poverty Guidelines, 2018).

characteristics of utility assistance receiving population in the Salvation Army Metro Phoenix area (n = 1,666), their key characteristics (low-income, minority groups, and living along) empirically correspond with major heat vulnerability variables known from the literature that lead to indoor heat-related deaths and illnesses (Harlan et al., 2012).

Due to contractual requirements, the Salvation Army conducts in-person interviews for every family who applies and qualifies for utility assistance. Table 2 reports the in-person interview case distribution across the Salvation Army office locations. For the years 2015–2016 and 2016–2017, the Salvation Army served clients at 5 locations (Kroc Center, Phoenix Family Services, Phoenix Central Corps, Maryvale Corps, and Phoenix Citadel Corps). Due to a new centralization requirement and budget limits, the Salvation Army reduced their service locations from 5 to 2, which resulted in closing Phoenix Central Corps, Maryvale Corps, and Phoenix Citadel Corps Service Centers. By May 2017, all cases were directed to Kroc Center and Phoenix Family Services. From May 2016 to April 2017, 208 clients were interviewed at Kroc Center and 243 clients were interviewed at Phoenix Central Corps. After the office centralization, 255 clients were interviewed at Kroc Center and 97 cases were interviewed at Phoenix Family Services.

Fig. 2 shows the spatial distribution of the client interview assignment based on the zip code of the client. We can observe from the map that many clients were assigned to Salvation Army service locations far from their home. This distance could add additional financial stress because many clients may travel by public transportation to the interview location, which takes longer than car travel, and most clients would need to take unpaid time from work to make the interview in-person. We therefore aimed to characterize the pattern of the current interview assignment strategy to inform discussions about what does operational efficiency look like, and what methods might improve operational efficiency.

4.2. Spatial rebalance of the utility assistance system

Fig. 3 shows the address-based client interview assignment optimization results. To improve operational efficiency in this experiment, we reassigned all clients based on their physical home addresses (rather than zip code) and calculated shortest driving distance/time to a Salvation Army service location. For the sake of the analysis, we conservatively assumed all clients drove to the service locations based on the shortest path on the Freight Analysis Framework network (including highway and major arterials) in the Phoenix metropolitan area (FAF4 Network Database and Flow Assignment: 2012 and 2045 - FHWA Freight Management and Operations, 2018, p. 4), although we know anecdotally that many clients utilize public transportation.[1]

Based on the spatial optimization results in 2016-17, more clients were assigned to Maryvale Corps from Kroc Center and Phoenix Central Corps. The number of clients that assigned to Phoenix Citadel Corps and Phoenix Family Services remain the same. This change would require staff and processing capacity rebalance within the three service centers of the Salvation Army. In 2017–18, the spatial rebalancing results show that the Salvation Army should assign more clients, staffs, and processing capacity to the Phoenix Family Services rather than the Kroc Center because most of their clients came from the north side of the Phoenix.

[1] Salvation Army originally gave little consideration to transit lines when selecting their service provider locations, and greater consideration to where the locations are central to the communities of greatest need. This was determined relative to the aggregate of zip codes within the surrounding area as identified through Census 2010 income and demographic data, not transportation patterns. For these reasons, our optimized allocation does not assume transit, because it is a conservative estimate. For clients who use transit, the savings would be even greater. Therefore, the results avoid overinflating potential savings to families.

Tables 3 and 4 show how the address-based client assignment method improves overall system efficiency under these assumptions. During the May 2016 to April 2017 period, an address-based assignment method would have reduced driving miles by 1495.93 and 29.2 driving hours for 632 clients over the current zip code-based assignment approach. The average client mileage travel would have been reduced from 7.28 miles/client to 4.91 miles/client (a 32.5% savings) and the average client driving time reduced from 8.4 min to 6 min (a 31.4% savings). After the office centralization, an address-based assignment method would save clients 416.70 driving miles and 14.1 driving hours for 352 clients. The average client mileage travel would be reduced from 11.07 miles/client to 9.89 miles/client (a 10.7% savings) and the average client driving time would be reduced from 13.8 min to 11.4 min (a 17.7% savings). The maximum client travel distance also decreases from 31.43 miles to 25.96 miles, and maximum driving time decreases from 34.8 min to 26.4 min in the year of 2016-17. After the Salvation Army reduced their service locations, the average client mileage travel in the model increased from 7.28 miles/client to 11.07 miles/client. Most of the clients would be assumed to travel longer distances to participate in the interview and receive utility assistance.

Although we have observed significant savings in travel distance/time based on the highway and major arterials, we recognize that many low-income families do not own cars and instead use public transportation. Using the public transportation is expected to take even longer than shortest path direct routes by car that our model assumptions are based upon, so our results will be conservatively biased. From our HeatMappers survey results from the Salvation Army (nine respondents in total), three of them responded that they used public transit to visit the Salvation Army for interview. The average travelling time was around 1–1.5 h. Two of them responded that they used personal cars to do the interview, and the average time was around 15–20 min. Although the sample size of the survey is relatively small, we certainly can conclude that the data experiment underestimates travel savings since many clients use public transit and would take a longer time to reach the interview location. This of course increases personal exposure to heat during summer months.

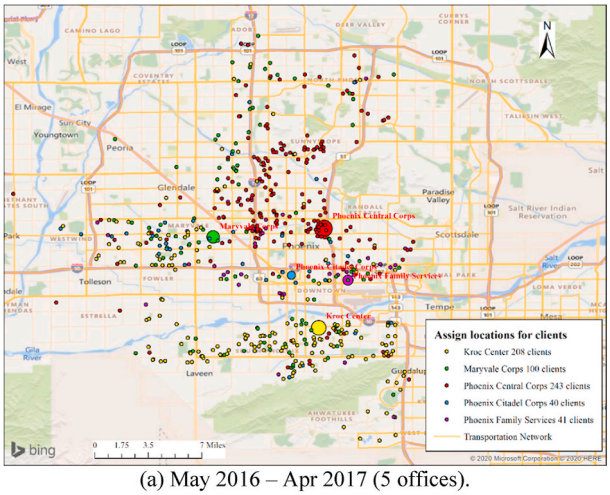
4.3. Temporal understanding of the utility assistance system

Table 5 shows the yearly utility assistance budget from May 2015 to April 2018. There is a significant decrease in both total monetary assistances provided and the number of cases from 2015 to 2018. Since the Salvation Army aims to maintain a similar amount of monetary assistance to each qualified applicant, only 352 families received utility assistance support from May 2017 to April 2018, compared to 682 families in 2015–2016 and 632 families in 2016–2017.

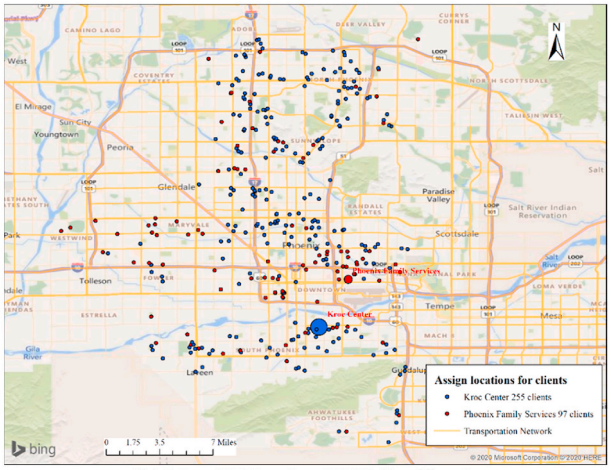
Specifically, our collaborative team analyzed the Salvation Army Metro Phoenix SHARE funding monthly reports from January 2017 to August 2018. We explored the date, the total amount of monetary assistance and the reason for rejection if not offered for each utility assistance application. This allowed us to compare the number of applicants, the total amount of money distributed and the total number of cases approved on monthly basis. Annual SHARE funds ($117,120.36 from September 2017 to August 2018) are operationally divided into twelve equal amounts that became the budget for each month ($9760.03). When that budget amount is reached, remaining clients are turned away due to insufficient funds. This financial information is presented alongside the number of clients that were approved and turned away each month to show budgeting decisions. While each month received 8.3% of the yearly budget, some months (February to April), as shown on Fig. 4, only saw 3% of the year's caseload while other months (September and October) shouldered over 15% of the cases. In the pie chart, the lighter shading reflects the portion of cases from that month that were actually awarded assistance; the remainder of each slice in the chart are cases that were qualified but turned away due to lack of funds allocated for the month.

Table 2
In-person interview case distribution summary.

Year	Kroc Center	Phoenix Family Services	Phoenix Central Corps	Maryvale Corps	Phoenix Citadel Corps	Total
May 2015–Apr 2016	96	186	191	113	96	682
May 2016–Apr 2017	208	41	243	100	40	632
May 2017–Apr 2018	255	97	0	0	0	352

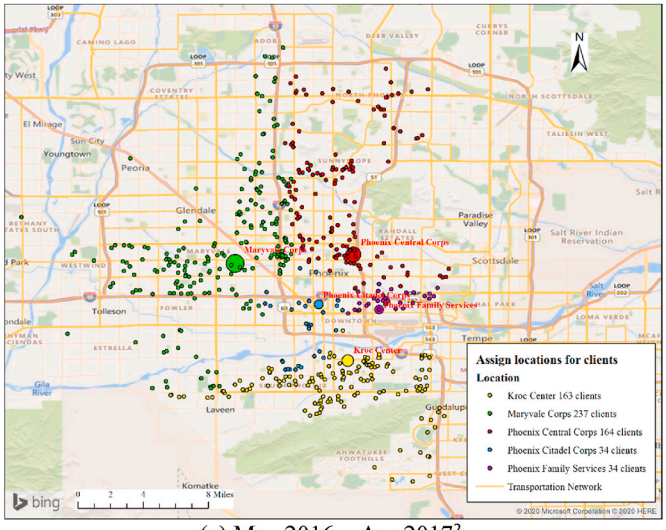


(a) May 2016 – Apr 2017 (5 offices).

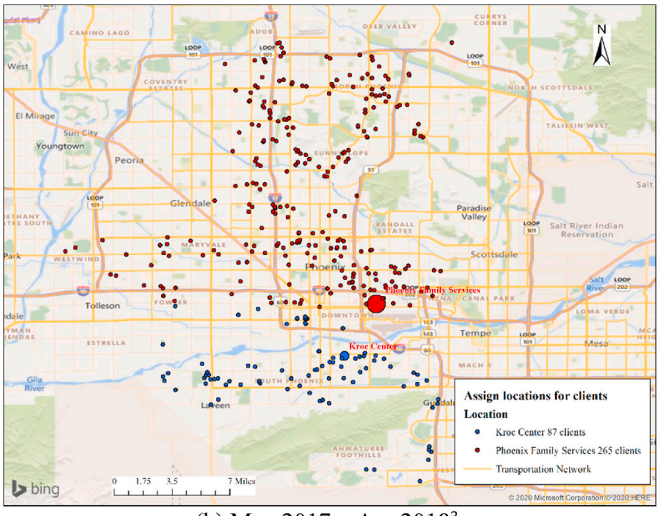


(b) May 2017 – Apr 2018 (2 offices).

Fig. 2. Zip code-based client assignment by the Salvation Army.



(a) May 2016 – Apr 2017[2].



(b) May 2017 – Apr 2018[3].

Fig. 3. Address-based client assignments.
(a) May 2016–Apr 2017. Video of the interactive map visualization can be found at: https://github.com/Resilience-ASU/SalvationArmyPaper/blob/master/Visualization/SalvationArmy-visual-201617.mp4.
(b) May 2017–Apr 2018. Video of the interactive map visualization can be found at: https://github.com/Resilience-ASU/SalvationArmyPaper/blob/master/Visualization/SalvationArmy-visual-201718.mp4.

While the monthly budget is a consistent amount, the number of households who request utility assistance varies greatly across the calendar year, given weather patterns and AC demand. This aspect is addressed in greater detail in Fig. 5. The blue portions represent the number of cases that the Salvation Army was able to assist. The numbers vary because the dollar amount awarded to each case varies, but each month the Salvation Army gives the same utility assistance dollar amount to their clients because of the evenly distributed budget. The red segments represent the number of cases that were qualified to receive assistance but were turned away due to lack of funds in that monthly budget. Considering the Phoenix heat during the long-lasting summer from May to September (utility bills from June to October) and its temperate winters, the flux in caseload numbers is not surprising. Because the Salvation Army's budget is not distributed to account for these seasonal changes, they cannot fulfill the high utility assistance requests during the peak summer seasons. The resulting pattern shows that only two households were turned away in March 2018, while they turned away 447 families in August 2017. The emotional fatigue of turning away applicants was taking its toll on many of the social workers interviewing applicants for the Salvation Army. In 2018, the Salvation Army implemented a phone management system to automatically notify "out-of-fund" status to applicants when a number of calls is reached. This system provided relief to the Salvation Army workers by reducing the qualified lack-of-funds turn away case numbers significantly. However, this also meant that system was truly "first come, first serve" rather than a system based on extreme need or risk. This narrative demonstrates a mismatch across the timing of supply and demand and reveals

Table 3
Client travel efficiency optimization from May 2016 to April 2017.

		Zip code-based assignment	Address-based assignment	Savings
Distance (miles)	Sum	4598.60	3102.67	1495.93
	Mean	7.28	4.91	32.5%
	Max	31.43	25.96	17.4%
Gas ($0.15/mile)	Cost	$689.79	$465.40	$224.39
Time (minutes)	Sum	5580	3828	1752
	Mean	8.4	6	31.4%
	Max	34.8	26.4	24.1%

Table 4
Client travel efficiency optimization from May 2017 to April 2018.

		Zip code-based assignment	Address-based assignment	Savings
Distance (miles)	Sum	3898.24	3481.54	416.70
	Mean	11.07	9.89	10.7%
	Max	46.33	46.33	N/A
Gas ($0.15/mile)	Cost	$584.74	$522.23	$62.51
Time (minutes)	Sum	4770	3924	846
	Mean	13.8	11.4	17.7%
	Max	42.6	42.6	N/A

Table 5
Monetary assistance summary.

Year	Case number	Total money amount	Mean	Min	Max
May 2015–Apr 2016	682	$182,187.42	267.14	0	400
May 2016–Apr 2017	632	$159,109.83	251.76	0	400
May 2017–Apr 2018	352	$90,759.97	257.84	24.75	509.12

the extent of impact of the scarce resource context of distribution patterns, a phenomenon that other utility assistance providing-organizations in the community anecdotally report, as well. The main reason for this mismatch is purported to relate to meeting donor and funding agency requirements.

5. Discussion

The joint presentation of these findings by our team of university researchers and Salvation Army leaders to the whole community of organizations sparked a fruitful conversation with the broader utility assistance network in Maricopa County. While many were aware that many qualified cases were being turned away, and that clients travel to participate in the interviews might represent an added burden, the empirical analysis afforded by one organization's dataset helped numerically characterize the challenges present in the overall utility assistance system. Although families can receive the support every 12 months from the Salvation Army, there were only 31 families which came back and received the utility assistance again in the period of May 2015–April 2018. They may, however, have requested support from other organizations that offer assistance. Beyond simply requesting more money to assist more cases, an immediate tactic within the purview of providers is to understand and improve the overall operational efficiency of the utility assistance system, such as that modeled by the Salvation Army's multiple sites. The collaborative research made visible

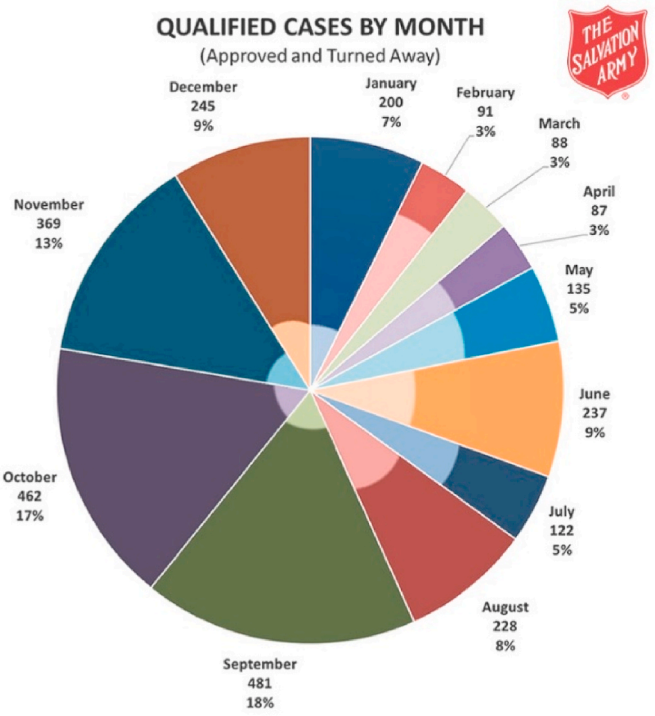


Fig. 4. Current monthly budget distribution and monthly qualified cases of the Salvation Army (Data from September 2017 to August 2018).

some of the features of the system, including constraints as well as trade-offs that heat resilience strategies may offer.

Regarding applications that the knowledge co-producing partner Salvation Army made within their own organization as a result of the findings, we report mixed outcomes. The results emanating from the temporal analysis turned out to be more easily incorporated into operations than the results generated from the spatial analysis – perhaps in part because they were more deeply transformative. As a result of this joint work, Salvation Army was able to combine their internal utility assistance resources together with funds for rental assistance to have overall greater availability of resources during hot summer months when demand mismatched supply. Instead of *reallocating* resources to meet higher demand timing patterns, they took upon a new effort to request and generate a supplemental fund to better support the summer demand without taking away from the needs in other months.

Spatial mismatch of supply and demand seems obvious, but it was earlier perceived as a different kind of problem to Salvation Army (perhaps characterized as a problem of lack of data). In other words, the nature of the problem being a mismatch *was made obvious* through the process of this partnership. The spatial optimization revealed a new opportunity for innovation of efficiencies to the clients, even if changing the system required a lot more than investment in knowledge, but investment in capital to transition phone lines, enlist human resources and provide training, operational changes, which all bore a particular transition cost that simply was an amount of resource that did not exist to do.

Regarding the spatial dimension of efficiency, switching from the current zip code-based system to the more efficient address-based system requires a software system infrastructure update in the Salvation Army and further staff training. Furthermore, the Salvation Army has multiple offices operating in the large Phoenix metropolitan area such as Tempe office, Glendale office, and Sun City office. To further improve the operational efficiency of the Salvation Army, a spatial optimization method would need to be used across all the Salvation Army offices in the Phoenix Metropolitan area. Such a solution would require more collaboration and information sharing within the Salvation Army Metro Phoenix to reduce the travel burden on clients, but such allocation may

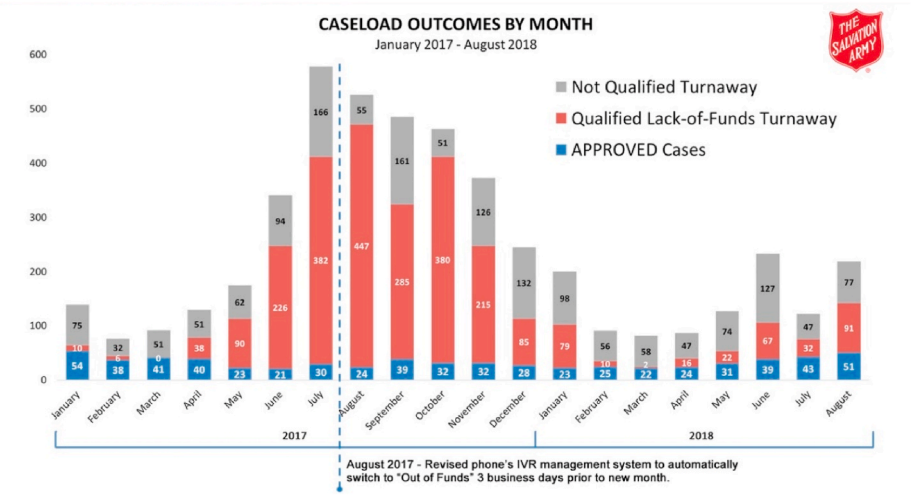


Fig. 5. Caseload of the Salvation Army utility assistance program.

or may not overall better help clients.

Large scale change requires large scale input beyond the city core office of the Salvation Army (local unit). Before any of the findings identified in our joint research gained sufficient traction, there was a change in top leadership which rendered the possibility of this kind of longer-term large-scale change immediately infeasible. However, the knowledge still had an impact and could create such change in the future: implementation of the knowledge findings remains on the table if the kind of systems change opportunity arises. The Salvation Army was able to inspect a new way to look at efficiencies, namely not in terms of the efficiencies of their own operations but redefining it in terms that clients/families endure. Our partners reported it allowed them to think differently about how to connect to families seeking utilities assistance: "data drove that change in perspective." In fact, the broader utility assistance network has adopted a vision and a plan to construct an opt-in one-stop system to support clients and organizations across the region. One of the lessons integrated into the design will be to incorporate address-specific referrals. Some suggestions to advocate for elimination of an in-person interview have even surfaced.

Some other reasons emerge for why this quantitative analysis alone is valuable only when part of a community research collaboration such as the knowledge exchange in this study. Since most client families by time of application have reached a crisis situation, the personal relationships that the Salvation Army personnel offer to beneficiaries become critical. Referrals to other complimentary services that are often needed may take more than distance into account, such as the multiple needs of clients, trust, and the need to offer connections that serve multiple needs beyond the utility assistance without making referrals then to multiple locations. The performance of the referral location, whether that would be to a particular Salvation Army office location, or another organization within the system, must match the specific needs of the client.

Regarding the temporal dimension of efficiency, one concern raised relates to the Salvation Army's caseworkers uneven need to turn away applicants repeatedly for an extended season. Hypothetically, if the year's budget had been distributed according to the caseload percentages shown in Fig. 4 (for example, January would get 7% of the budget, February 3%, etc.), then each month they would have turned away a consistent proportion of cases. Taking the 2,745 cases represented in the pie chart year and the 389 cases that were approved in that time, 14% of cases were approved and 86% were turned away. While the rejection number is obviously higher than desired, being able to spread out rejections proportionally throughout the year would mean that caseworkers are at least able to say yes for 14% of the time in any given month, instead of facing back to back months with only 5% approvals. Of course, it is hard to know in advance what the precise caseload distribution will be for a year, but the seasonality of the demand is predictable and could be anticipated in order to prevent "battle fatigue" of saying no to needy families. At present this is not practical to implement due to funding source constraints that may present individually, or through the often complex and uncertain budgeting framework of braided sources that often sustain organizations in this sector.

The other large concern regarding timing at the systems scale is the one most directly related to heat vulnerability and death. To turn down someone's request for assistance paying their utility bill during the temperate spring in March, while unfortunate, does not typically carry the same magnitude of health risks as a request that is turned down for utility assistance in the infamous summer heat of Phoenix in August. Families that are unable to pay utility bills to cover their AC use in the summer are at dramatically increased risk of heat exposure and death at temperatures above 40 degrees C, according to the Maricopa County Public Health Department. The budget and caseload distribution findings by month prompt the question of whether reducing the allocation of funds for temperate months and moving more funding towards the summer months. Although it may mean rejecting more households during temperate months, it also means that funds would be available to assist those facing much riskier consequences. In this way, the efficiency concerns may give way to issues of efficacy, where resources could be strategically aligned to meet the needs of the most heat-vulnerable families. Again, the uncertain variability of donor funds and some of the constraints on budgeting need to be resolved to implement such a resilience strategy.

Limitations and future work of this research are important to note. First, we observed that a large population who receives utility assistance lives in the north Phoenix area. A more centralized provider-client system in the Salvation Army and a larger utility assistance network is necessary to improve operational methods to reduce travel distances of the potential qualified clients. Furthermore, we assume all the clients drove to the service location to do the interview. This is not a realistic assumption either for this one partner organization nor the system as a whole, since many low-income households cannot afford a car. Public transportation networks (bus and light rail network) need to be used to improve the analysis results in future studies. In addition, there are other types of assistances (i.e. rental assistance) provided by the Salvation Army which required similar application and interview processes, and provided innovative ways for implementing findings. More analysis can be done to obtain a better overall understanding of the entire Salvation Army operational system and the network of providers as a whole. Lastly, many NGOs and charitable organizations struggle with an imbalanced service demand, limited resources, and shortage of data

analytical expertise. The methodologies we used in this research can be widely extended to help solve similar resource constraint problems for services they provide beyond utility assistance but also food insecurity, housing support, and labor requirements in other regions of the world.

6. Conclusions

Our co-designed research provided new insights and solutions to service the utility assistance population and improve the overall system efficiency of the entire provider-client system. The results help the Salvation Army better consider how to assign their human forces within their organization, as well as reduce low-income and fixed-income population's financial burden during the process of requesting assistance. The lessons learned directly inform tactical decision making for the operations of the Salvation Army to improve efficiency, and supporting the development of strategic thinking about how operations can improve efficacy, whereby the most heat-vulnerable are better served. Results were shared with the entire utility assistance network of organizations, and the model demonstrated to the community of providers the value of sharing internal data to analyze service provision across space and time. These insights were taken up collectively in plans by the network to assess the feasibility of designing a single-point client intake system for the area. Building on these results, plans now currently include intention to incorporate an address-based approach during intake referral steps, as well as paying attention to temporal patterns of funding availability across the network as a whole. It is possible that organizations could advocate for the release the requirement of client interviews if the single-point client intake system collects enough useful information, if they choose to do so outside of a case-management framework. Demonstrating that utility assistance providers are optimizing and strategically deploying currently limited resources strengthens the case that demand outstrips need for heat resilience measures in Maricopa County.

Our findings and subsequent discussions solidified the importance of considering both the "when" as much as the "where" of utility assistance distribution to the greatest benefit, discussions that are ongoing but better informed thanks to a data-rich analytical collaboration. The seasonality and locations of the demand for utility assistance, and the magnitude of health risks as a consequence of its unavailability, must be key components of informing both tactical and strategic decisions around the distribution of utility assistance throughout the year and across the area. This ongoing work takes seriously the imperative of deep engagement of community organizations on the research team and among study authors. Such data collaboration can also help build organizational social cohesion, which contributes in and of itself to greater community resilience.

CRediT authorship contribution statement

Qunshan Zhao: Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Chelsea Dickson:** Formal analysis, Writing - original draft, Visualization. **Jowan Thornton:** Conceptualization, Writing - review & editing, Resources. **Patricia Solís:** Conceptualization, Writing - original draft, Writing - review & editing, Supervision, Project administration. **Elizabeth A. Wentz:** Conceptualization, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

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References

2017 Poverty Guidelines. (2018). January 12). ASPE https://aspe.hhs.gov/2017-poverty-guidelines.

Barthel, S., & Isendahl, C. (2013). Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities. *Ecological Economics, 86*, 224–234. https://doi.org/10.1016/j.ecolecon.2012.06.018.

Bec, A., McLennan, C., & Moyle, B. D. (2016). Community resilience to long-term tourism decline and rejuvenation: A literature review and conceptual model. *Current Issues in Tourism, 19*(5), 431–457. https://doi.org/10.1080/13683500.2015.1083538.

Beheshtian, A., Donaghy, K. P., Richard Geddes, R., & Oliver Gao, H. (2018). Climate-adaptive planning for the long-term resilience of transportation energy infrastructure. *Transportation Research Part E: Logistics and Transportation Review, 113*, 99–122. https://doi.org/10.1016/j.tre.2018.02.009.

Cai, H., Lam, N. S. N., Zou, L., & Qiang, Y. (2018). Modeling the dynamics of community resilience to coastal hazards using a Bayesian network. *Annals of the Association of American Geographers*, 1–20. https://doi.org/10.1080/24694452.2017.1421896.

Church, R. L., & Murray, A. T. (2009). *Business site selection, location analysis, and GIS.* Wiley.

Cook, J. T., Frank, D. A., Casey, P. H., Rose-Jacobs, R., Black, M. M., Chilton, M., et al. (2008). A Brief indicator of household energy security: Associations with food security, child health, and child development in US infants and toddlers. *Pediatrics, 122*(4), e867–e875. https://doi.org/10.1542/peds.2008-0286.

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2014). The geographies of community disaster resilience. *Global Environmental Change, 29*, 65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for Benchmarking Baseline conditions. *Journal of Homeland Security and Emergency Management, 7*(1). https://doi.org/10.2202/1547-7355.1732.

Daskin, M. S. (2013). Network and discrete location: Models, algorithms, and applications. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=601808.

Day, R., Walker, G., & Simcock, N. (2016). Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy, 93*, 255–264. https://doi.org/10.1016/j.enpol.2016.03.019.

FAF4 network Database and Flow assignment: 2012 and 2045. (2018). FHWA Freight management and operations. https://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf4/netwkdbflow/index.htm.

Fraser, A. M., Chester, M. V., Eisenman, D., Hondula, D. M., Pincetl, S. S., English, P., et al. (2017). Household accessibility to heat refuges: Residential air conditioning, public cooled space, and walkability. *Environment and Planning B: Urban Analytics and City Science, 44*(6), 1036–1055. https://doi.org/10.1177/0265813516657342.

Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine, 63*(11), 2847–2863. https://doi.org/10.1016/j.socscimed.2006.07.030.

Harlan, S., Declet-Barreto, J., Stefanov, W. L., & Petitti, D. (2012). Neighborhood effects on heat deaths: Social and environmental predictors of vulnerability in Maricopa county, Arizona. *Environmental Health Perspectives, 121*(2), 197–204. https://doi.org/10.1289/ehp.1104625.

Hernández, D. (2016). Understanding 'energy insecurity' and why it matters to health. *Social Science & Medicine, 167*, 1–10. https://doi.org/10.1016/j.socscimed.2016.08.029.

Janssen, B. M., Van Regenmortel, T., & Abma, T. A. (2011). Identifying sources of strength: Resilience from the perspective of older people receiving long-term community care. *European Journal of Ageing, 8*(3), 145–156. https://doi.org/10.1007/s10433-011-0190-8.

Kovats, R. S., & Hajat, S. (2008). Heat stress and public health: A critical review. *Annual Review of Public Health, 29*, 41–55.

Li, K., Lam, N. S. N., Qiang, Y., Zou, L., & Cai, H. (2015). A cyberinfrastructure for community resilience assessment and visualization. *Cartography and Geographic Information Science, 42*(sup1), 34–39. https://doi.org/10.1080/15230406.2015.1060113.

Low Income Home Energy Assistance Program (LIHEAP). (2019). Office of community services | ACF. https://www.acf.hhs.gov/ocs/programs/liheap.

Maricopa County Public Health Department. (2019). Heat reports | Maricopa county, AZ. https://www.maricopa.gov/1858/Heat-Surveillance.

National Weather Service. (2018). Weather related fatality and injury statistics. https://www.weather.gov/hazstat/.

Our Mission. (2019). Vision and values | the Salvation Army. https://www.salvationarmy.org.uk/our-mission-vision-and-values.

Our history. (2019). The Salvation Army. https://www.salvationarmy.org.uk/our-history.

Putnam, H., Hondula, D. M., Urban, A., Berisha, V., Iñiguez, P., & Roach, M. (2018). It's not the heat, it's the vulnerability: Attribution of the 2016 spike in heat-associated deaths in Maricopa county, Arizona. *Environmental Research Letters, 13*(9), Article 094022. https://doi.org/10.1088/1748-9326/aadb44.

Ram, R. (2014). Technology adoption for long-term drought resilience. *Journal of Water Resources Planning and Management, 140*(3), 384–392. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000329.

Shen, T., Howe, H. L., Alo, C., & Moolenaar, R. L. (1998). Toward a broader definition of heat-related death: Comparison of mortality estimates from medical examiners' classification with those from total death differentials during the July 1995 heat wave in chicago, Illinois. *The American Journal of Forensic Medicine and Pathology, 19*(2), 113–118.

Teller-Elsberg, J., Sovacool, B., Smith, T., & Laine, E. (2016). Fuel poverty, excess winter deaths, and energy costs in Vermont: Burdensome for whom? *Energy Policy, 90*, 81–91. https://doi.org/10.1016/j.enpol.2015.12.009.

The Salvation Army International - Statistics. (2019). https://www.salvationarmy.org/ihq/statistics.

US Census Bureau. (2018). 2013-2017 ACS 5-year estimates. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2017/5-year.html.

U.S. Census Bureau. (2017). American community survey 1-year estimates. Census reporter. http://censusreporter.org/profiles/31000US38060-phoenix-mesa-scottsdale-az-metro-area/.

U.S. Census Bureau. (2019). American FactFinder - results. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF.

U.S. Census Bureau QuickFacts. Phoenix city, Arizona. United States. (n.d.). Retrieved February 19, 2020 https://www.census.gov/quickfacts/fact/table/phoenixcityarizona,US/PST045218.

Vlachokostas, C., Achillas, C., Michailidou, A. V., & Moussiopoulos, N. (2012). Measuring combined exposure to environmental pressures in urban areas: An air quality and noise pollution assessment approach. *Environment International, 39*(1), 8–18. https://doi.org/10.1016/j.envint.2011.09.007.

Wang, C., Myint, S., Wang, Z., & Song, J. (2016). Spatio-temporal modeling of the urban heat island in the Phoenix metropolitan area: Land Use change implications. *Remote Sensing, 8*(3), 185. https://doi.org/10.3390/rs8030185.

Wentz, E. A., & Gober, P. (2007). Determinants of small-area water consumption for the city of Phoenix, Arizona. *Water Resources Management, 21*(11), 1849–1863. https://doi.org/10.1007/s11269-006-9133-0.

Zhang, C., & Lin, Y. (2012). Panel estimation for urbanization, energy consumption and CO2 emissions: A regional analysis in China. *Energy Policy, 49*, 488–498.

Zhao, Q., Sailor, D. J., & Wentz, E. A. (2018a). Impact of tree locations and arrangements on outdoor microclimates and human thermal comfort in an urban residential environment. *Urban Forestry and Urban Greening, 32*, 81–91. https://doi.org/10.1016/j.ufug.2018.03.022.

Zhao, Q., Yang, J., Wang, Z.-H., & Wentz, E. (2018b). Assessing the cooling benefits of tree shade by an outdoor urban physical scale model at Tempe, AZ. *Urban Science, 2*(1), 4. https://doi.org/10.3390/urbansci2010004.

Zou, L., Lam, N. S. N., Cai, H., & Qiang, Y. (2018). Mining twitter data for improved understanding of disaster resilience. *Annals of the Association of American Geographers*, 1–20. https://doi.org/10.1080/24694452.2017.1421897.